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TELEMETRY SYSTEM FOR EVALUATION OF BURN PROTECTION IN FULL-SCALE FUEL FIRE MANIKIN EXPOSURES

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An eighteen channel PAM/FM (Pulse Amplitude Modulated/Frequency Modulated) telemetry system was developed for measuring temperature rise on the surface of a manikin beneath protective clothing for full-scale fuel fire exposures in completely enveloping flames. Thermistors are used as temperature sensors at various locations on a manikin surface and backed by material of known thermal properties in order to correlate temperature rise with skin burn damage. The transmitted signals are recorded on analog magnetic tape

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and converted to a digital format for computer analysis.

The clothed manikin is passed through an Aviation Gasoline fire for three seconds ~~(references~~ 1 & 2) with the telemetry system recording data during this period. Temperatures are analyzed at 0, 1, 2 and 3-second intervals with voltage outputs from the thermistors being converted to resistance readings and temperature readings by equations developed from curves of thermistor characteristics.

Experimental results with respect to burn prediction are in agreement with data obtained by analysis of vesicant papers calibrated radiometrically to correlate with temperature-time effects productive of burns in living tissue. To date 12 full-scale fuel fire tests have been conducted using the telemetry system and the performance of this system has exceeded original expectations in many respects such as sensitivity, accuracy and freedom from interference by ionizing gases within the flames (reference 3).

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INTRODUCTION

An eighteen-channel PAM/FM (Pulse Amplitude Modulated/Frequency Modulated) telemetry system was developed for measuring temperature rise on the surface of a manikin beneath protective clothing for full-scale fuel fire exposures in completely enveloping flames. The telemetry system within the manikin consists of transducers, low level commutator, oscillator, transmitter, battery pack and signal conditioning circuitry. The transmitted signals are received, demodulated and recorded on analog magnetic tape at a remote location. The transducer data can be viewed on an oscilloscope and transferred to an oscillographic record or a digital tape for computer analysis. Initially, 30 gauge copper-constantan thermocouples were installed on a manikin for temperature measurements at 18 locations. The manikin being constructed of different thicknesses of fiberglass and wood made it impractical to correlate the temperature measurements to human skin burns. A second approach was to install thermocouples on leather patches in order to correlate the rate of heating with that of human skin and compare results with the established procedure for prediction of skin burns in full-scale fuel fires; namely, analysis of vesicant papers at the same locations on the manikin surface under protective clothing. At this point it was decided that the sensitivity of the entire system needed upgrading because the full-scale input to the low level commutator was approximately 10 millivolts or 200°C. This meant that a more sensitive commutator was required, or amplification of each channel, or transducers with improved outputs. The latter was chosen as the most efficient direction to take because replacement of the low level commutator would require redesign of an already sensitive system, and amplification of each channel would require additional space within the manikin for stable low drift DC amplifiers operating over an extreme temperature range. The first thermistors chosen were epoxy-coated spheres 2.4 mm in diameter, weighing 0.0625 grams, and having a resistance of 3000 ohms at 25°C. It was immediately apparent that these thermistors did not exhibit adequate frequency response for short term fuel fire exposures of 3 seconds because of a maximum time constant of 10 seconds in still air. In the final configuration a thermistor called a Thinistor, manufactured by Victory Engineering Corporation (VECO), was chosen for its excellent frequency response and low resistance. It has a 0.3 to 0.4 second maximum time constant in still air and a resistance of 500 ohms at 25°C. The Thinistor, which is 3 mm square, 40 microns thick, and sintered to a 0.0254 mm nickel foil, is mounted on a leather patch for burn injury assessments.

MATERIALS AND METHOD

The manikin is instrumented with 18 thermistors (VECO Thinistors) as illustrated in Figure 1. A schematic of the telemetry and associated electrical equipment is shown in Figure 2. The manikin chest cavity contains the transducer circuitry and battery, commutator, oscillator, and transmitter. The antenna is mounted above the neck in place of the head and a 28 volt battery pack is mounted in the lower trunk. The Thinistors are glued with a thin film of Duco cement on leather patches so that the temperature data can be correlated with skin burn assessments at locations illustrated in Figure 1. The receiver, discriminator, amplifier, oscilloscope and analog magnetic tape unit are located in a panel truck or table outside the fuel fire pit enclosure. The oscilloscope is used to monitor the data during and after an exposure by visual inspection of each channel's displacement. The crane position indicator places a signal on analog magnetic tape corresponding to four physical locations of the manikin within the fire at 0, 1, 2, and 3 seconds' exposure. The procedure before conducting the telemetry portion of each experiment consists of measuring the excitation voltage across the transducers and shorting out and recording each Thinistor output on analog magnetic tape. After a run is completed, two types of data analysis can be performed. One system transfers the analog magnetic tape output to an oscillographic record for analysis. The displacement of each channel can be measured at selected intervals and the corresponding millivolt output established. Readings can be analyzed for any time or any increment during the period that the magnetic tape recorder is operating either before, during or after a fuel fire exposure. The second system automatically analyzes the analog magnetic tape output by computer conversion into a digital format for computer analysis. Each system generates data which correspond to millivolts of output for each Thinistor at specific intervals. This is accomplished by measuring the displacement between zero output and the peak output of the Thinistors. Knowing the corresponding millivolt output required to generate this displacement, the millivolt output of each channel can be determined as described by equation 2. Having the millivolt output of each Thinistor at the specified interval, a computer program converts the data to resistance readings by using equation 4 and then to temperature readings by using equations 5 through 10, which describe curve No. 2 in VECO Product Bulletin MVM 1994A, a semilogarithmic plot of Resistance Ratio, $R(T)/R(25^{\circ}C)$ vs. Temperature $^{\circ}C$. The $150^{\circ}C$ point on the VECO curve is obtained by extrapolation. A 10 millivolt signal corresponds to a temperature of $22.66^{\circ}C$ and a 1 millivolt signal to $95.88^{\circ}C$.

$$\frac{12.6 \text{ millivolts}}{Y \text{ cm}} = \frac{V_T \text{ millivolts}}{Z \text{ cm}} \qquad \text{Eq. (1)}$$

$$V_T = \frac{12.6\ Z}{Y} \qquad \text{Eq. (2)}$$

12.6 = Full-scale input, peak reference
V_T = Voltage drop across Thinistor, R_T
Y = Displacement between zero reference and peak reference
Z = Displacement between Thinistor output and zero reference

$$V_S = I\,(R_F + R_T) \text{ and } I = V_T/R_T \qquad \text{Eq. (3)}$$

$$R_T = \frac{V_T R_F}{V_S - V_T} \qquad \text{Eq. (4)}$$

V_S = Voltage across R_F and R_T = .2843 volts
R_F = Resistor in series with Thinistor = 9000 ohms
R_T = Thinistor Resistance

$$^\circ C = \frac{7.28619 - \log_e R_T}{.04286} \qquad 0^\circ C \text{ to } 25^\circ C,\ 1460 \text{ ohms to } 500 \text{ ohms} \qquad \text{Eq. (5)}$$

$$^\circ C = \frac{7.11836 - \log_e R_T}{.03615} \qquad 25^\circ C \text{ to } 50^\circ C,\ 500 \text{ ohms to } 202.5 \text{ ohms} \qquad \text{Eq. (6)}$$

$$^\circ C = \frac{6.86174 - \log_e R_T}{.03102} \qquad 50^\circ C \text{ to } 75^\circ C,\ 202.5 \text{ ohms to } 93.25 \text{ ohms} \qquad \text{Eq. (7)}$$

$$^\circ C = \frac{6.60678 - \log_e R_T}{.02762} \qquad 75^\circ C \text{ to } 100^\circ C,\ 93.25 \text{ ohms to } 46.75 \text{ ohms} \qquad \text{Eq. (8)}$$

$$^\circ C = \frac{6.15381 - \log_e R_T}{.02309} \qquad 100^\circ C \text{ to } 125^\circ C,\ 46.75 \text{ ohms to } 26.25 \text{ ohms} \qquad \text{Eq. (9)}$$

$$^\circ C = \frac{5.87017 - \log_e R_T}{.02082} \qquad 125^\circ C \text{ to } 150^\circ C,\ 26.25 \text{ ohms to } 15.60 \text{ ohms} \qquad \text{Eq. (10)}$$

RESULTS AND DISCUSSION

Table I shows the Reference Temperatures, which are the Thinistor Temperatures before an exposure, and the changes in temperature as the manikin goes through the fuel fire. An additional refinement incorporated in the computer program, but not described in this paper, corrects the Thinistor Reference Temperatures to ambient by measuring each Thinistor resistance, calculating the corresponding temperature, and algebraically adding the difference between ambient and the calculated temperature to the Reference Temperature. Table I was generated by a computer digitizing the analog magnetic tape and providing voltage readings for Thinistor outputs. These voltages are converted to resistances using Equations 2 and 4 and then to temperatures using Equations 5 through 10. It is not within the scope of this paper to interpret the data in Table I, but it can be stated that the most severely burned area in this fuel fire would be the left leg, keeping in mind that leather heats at a rate three times that of human skin, and that for a three-second exposure, a temperature change of approximately 76°C from an initial temperature of 32.5°C must be reached before a severe burn is indicated. As a check of the telemetry system, a 108.14 ohm resistor was placed in channel 16. The telemetry system measured this resistance as 107.12 ohms corresponding to a temperature accuracy of 0.31°C, which is typical of the accuracy and sensitivity necessary for making human skin burn protection evaluations.

SUMMARY AND CONCLUSIONS

Experimental results with respect to burn prediction are in agreement with data obtained by analysis of temperature-sensitive vesicant papers calibrated radiometrically to correlate with temperature-time affects productive of burns in living tissue. To date, 12 full-scale fuel fire tests have been conducted using the telemetry system, and the performance of this system has exceeded original expectations in many respects, such as sensitivity, accuracy, and freedom from interference by ionizing gases within the flames.

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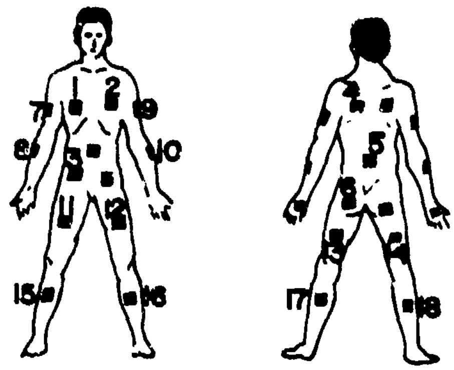

FIGURE 1. DISTRIBUTION OF THINISTORS

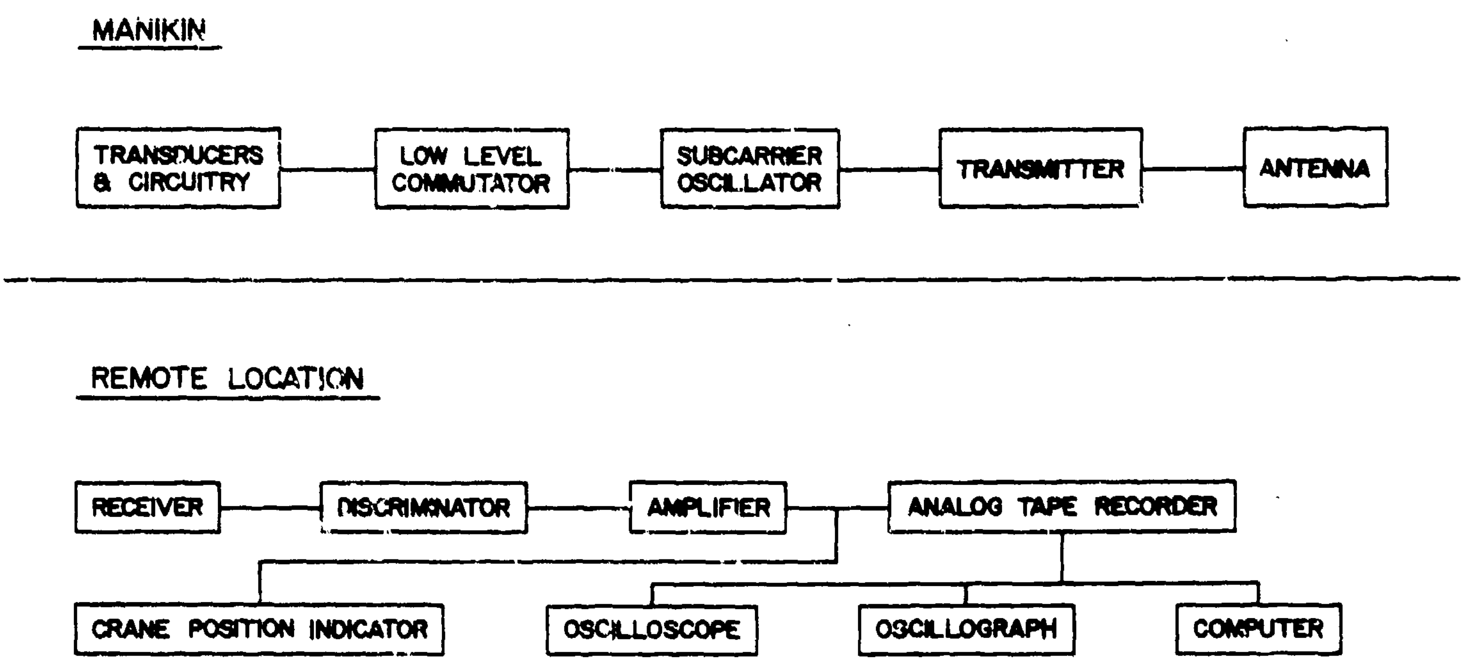

FIGURE 2. TELEMETRY SYSTEM

TABLE I - TEMPERATURES IN ^{o}C

		Change in Temperature from Reference			
Channel	Reference	0 second	1 second	2 second	3 second
1	31.92	1.86	4.76	14.97	15.54
2	31.52	1.76	2.61	0.94	2.41
3	25.81	1.52	4.44	9.48	12.30
4	34.57	-0.18	0.81	4.78	22.64
5	35.69	1.31	0.77	6.66	24.44
6	33.55	-1.26	1.18	14.88	36.46
7	35.45	1.20	1.96	10.66	7.54
8	36.43	1.99	8.79	20.25	12.56
9	39.89	1.79	3.03	8.71	8.24
10	34.08	2.94	14.55	28.05	24.28
11	39.26	3.75	11.12	15.22	11.37
12	42.78	6.91	25.82	42.62	54.60
13	36.30	1.57	7.70	33.08	68.52
14	36.25	0.71	6.84	22.99	21.91
15	37.92	5.39	15.03	21.96	30.73
16	* 70.53				
17	33.75	1.05	13.23	60.44	94.42
18	36.22	1.89	15.28	71.06	74.21

*Resistor for assessing accuracy of system

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